

CO₂ and CH₄ Measurements in São Paulo and their Relationship to Vehicular Emissions



Mediciones de CO₂ y CH₄ en São Paulo y su relación con las emisiones vehiculares

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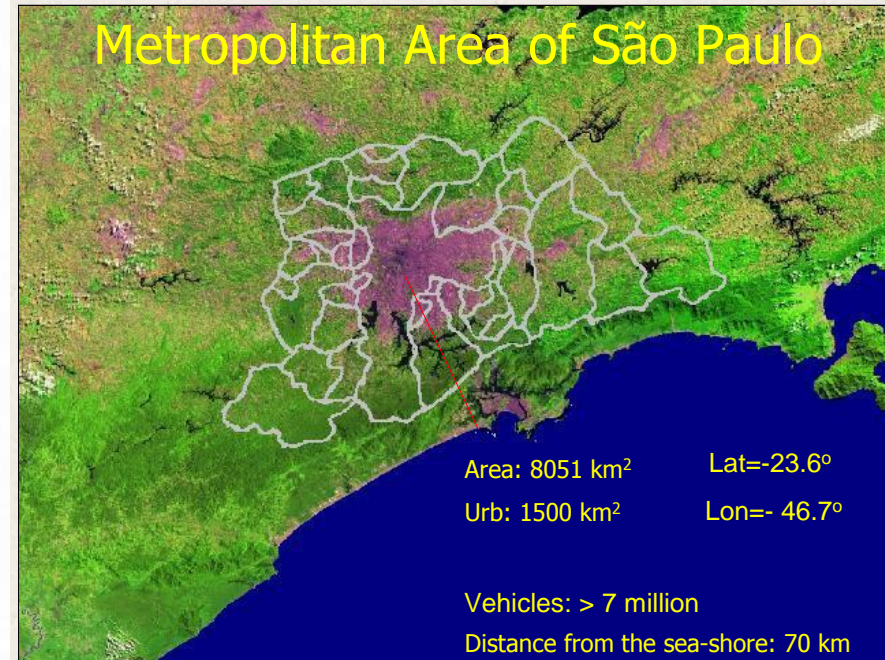
Characteristics of MASP

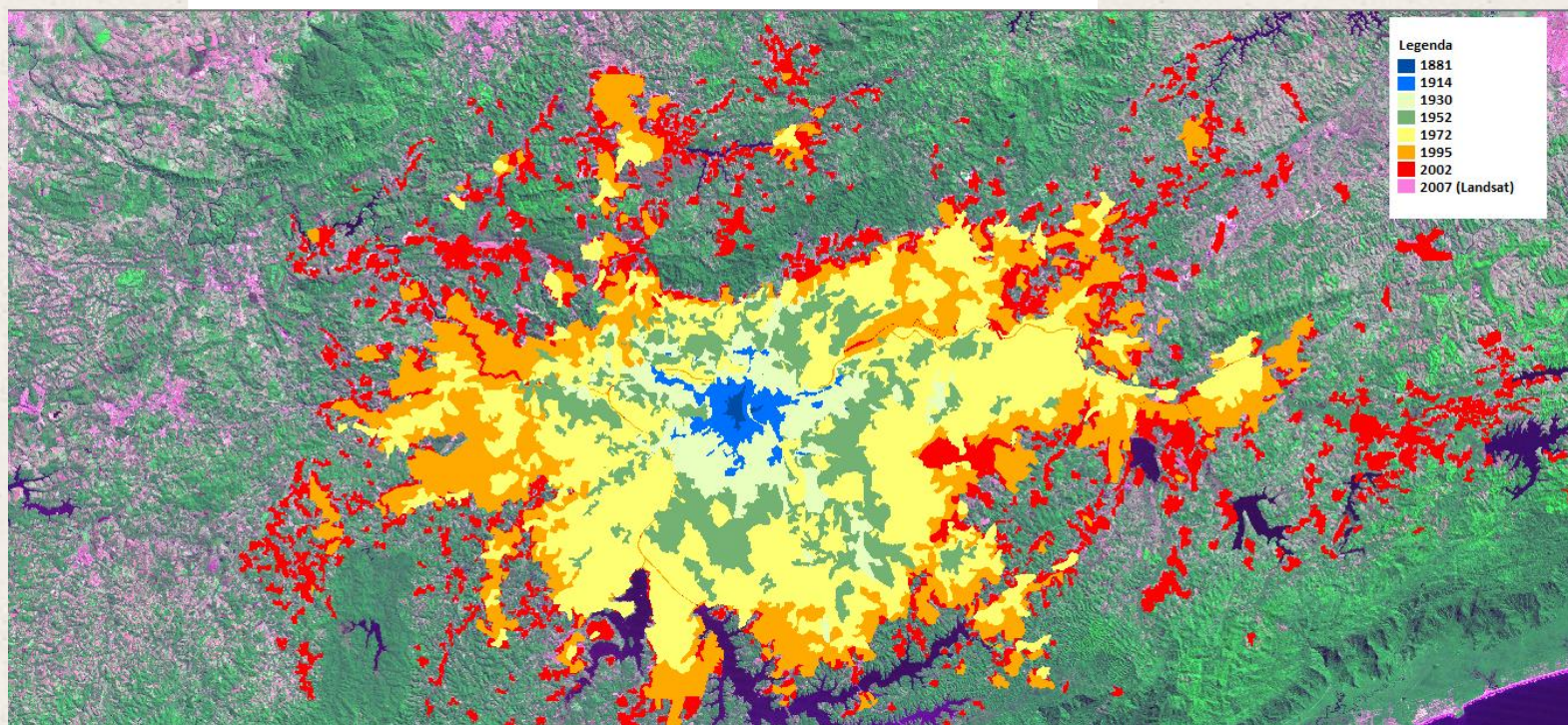
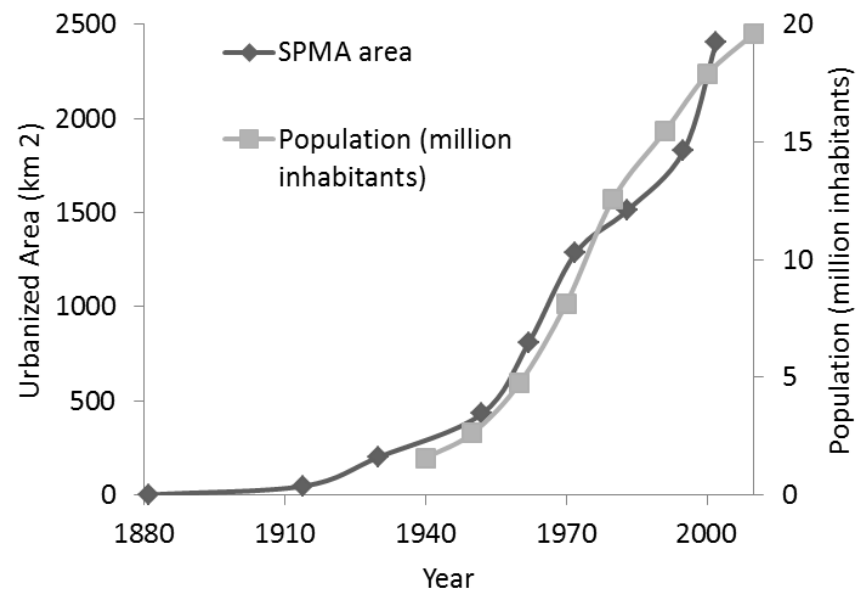
MASP= São Paulo city + 38 cities

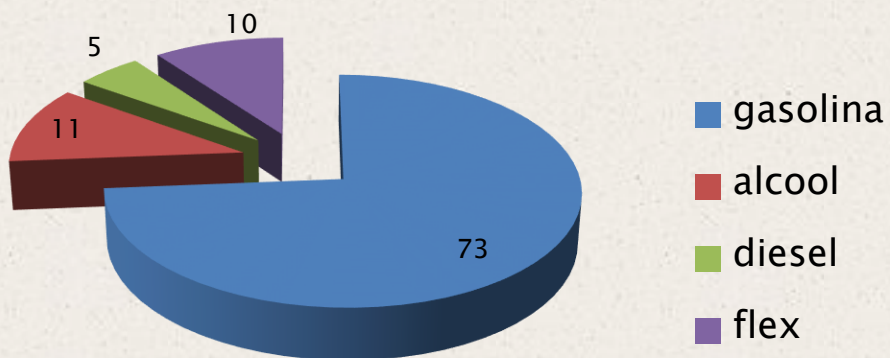
- 20 million inhabitants
- 7 million vehicles
- 2000 significative industrial plants



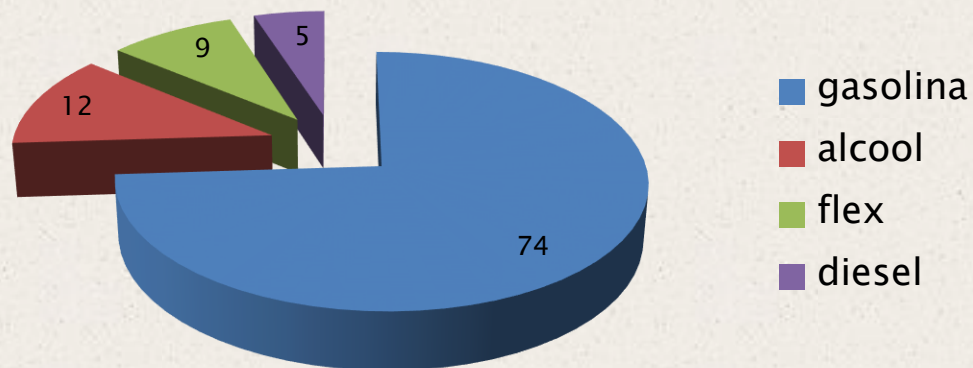
Metropolitan Area of São Paulo



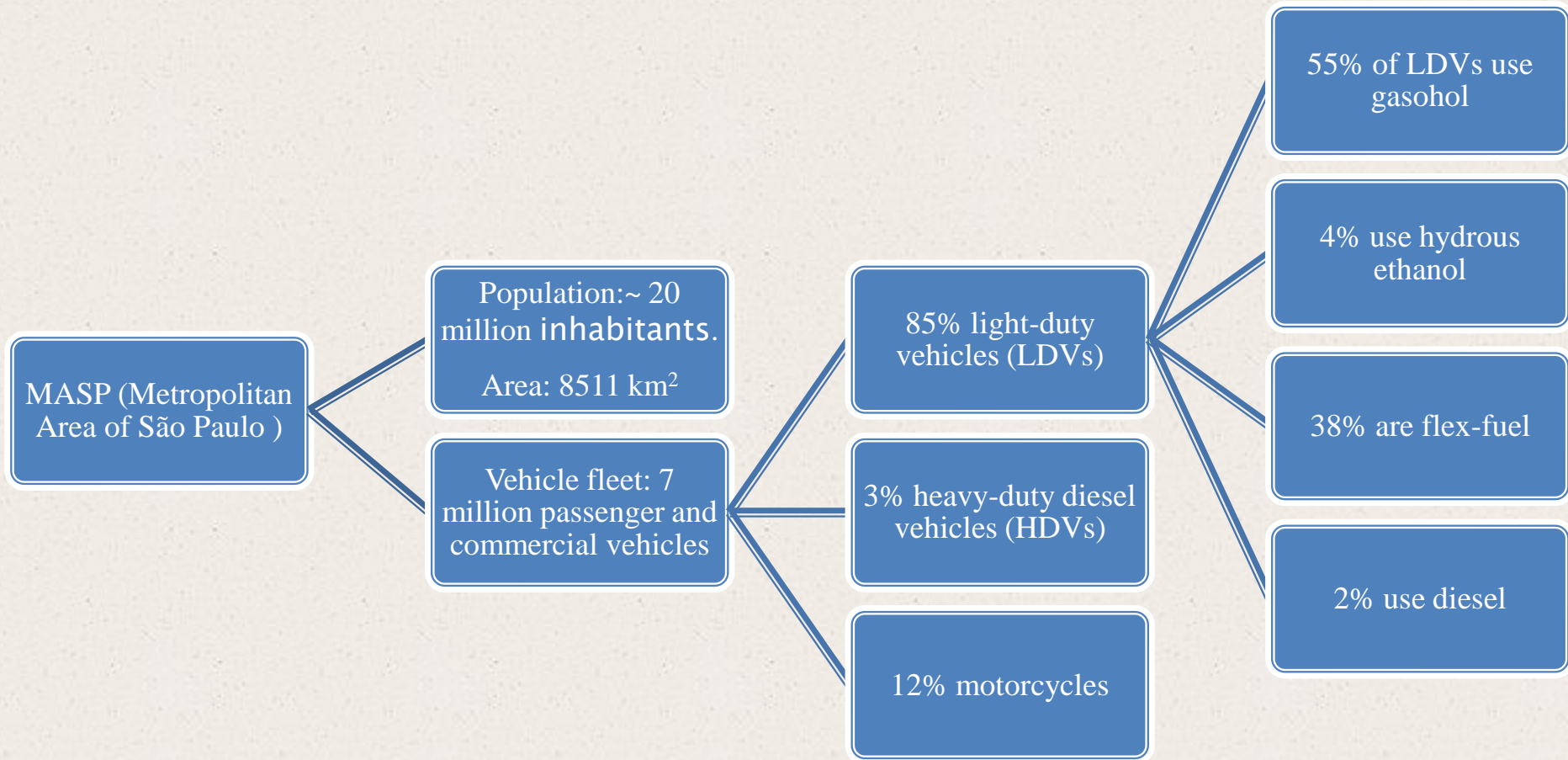




São Paulo Fleet



Brasil Fleet



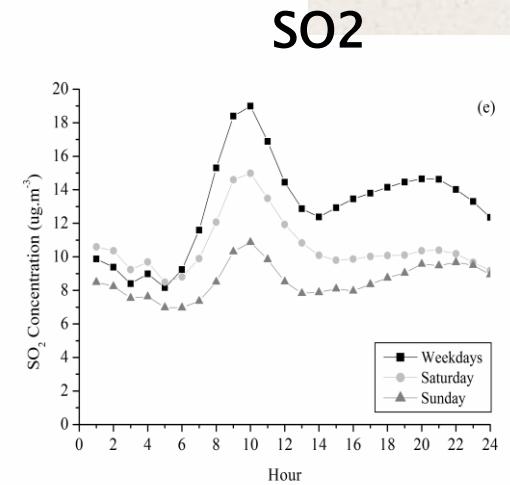
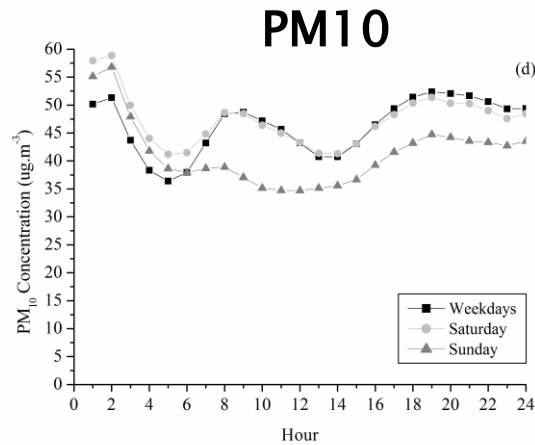
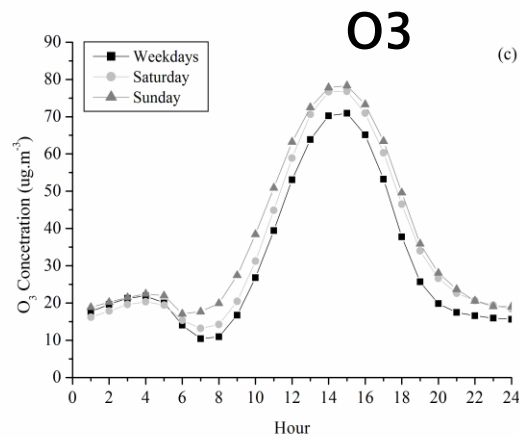
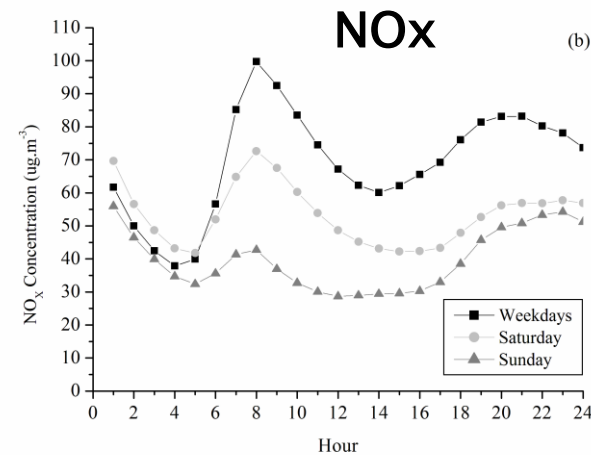
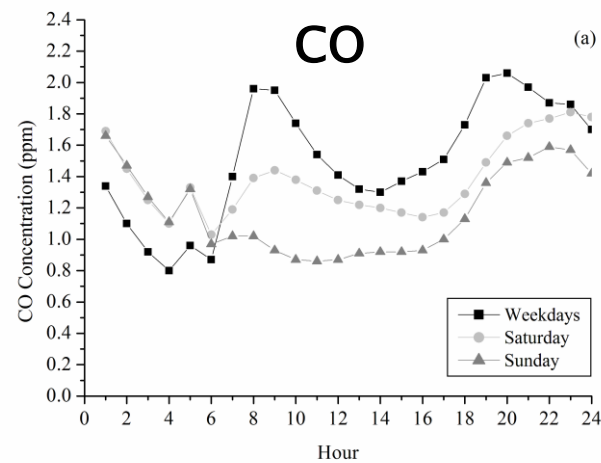
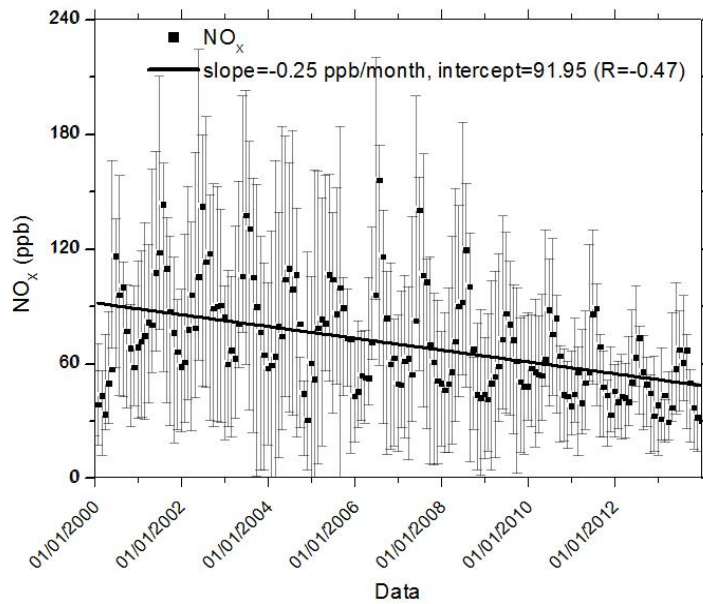
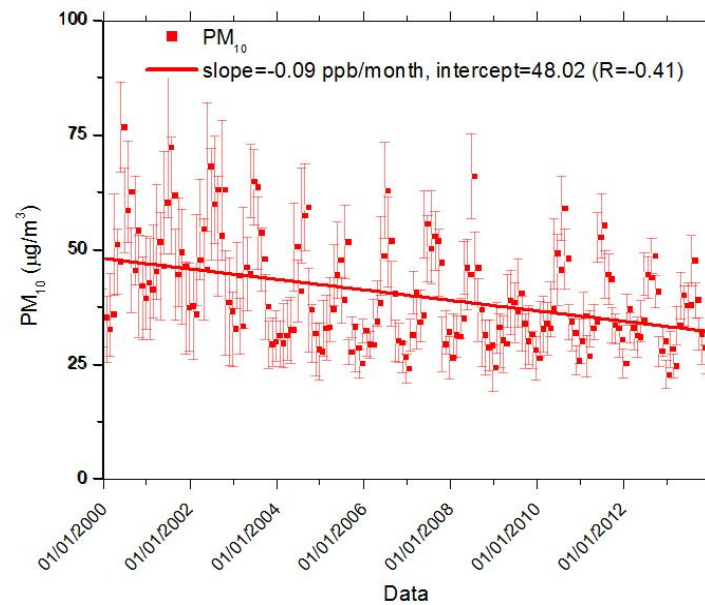


Figure 7: Mean concentrations of (a) CO (ppm), (b) NO_x ($\mu\text{g m}^{-3}$), (c) O₃ ($\mu\text{g m}^{-3}$), (d) PM₁₀ ($\mu\text{g m}^{-3}$) and (e) SO₂ ($\mu\text{g m}^{-3}$) measured in the monitoring stations in the MASP according to the hour of the Day and the day of the week, calculated during the period from 1996 to 2009.

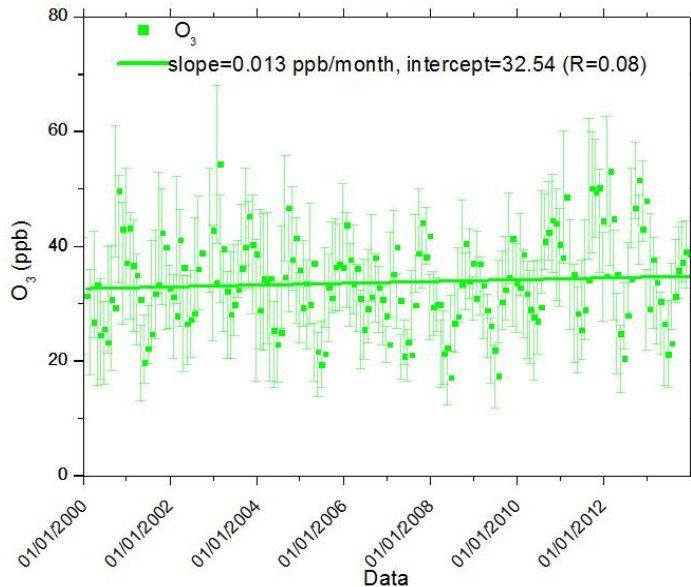
NO_x



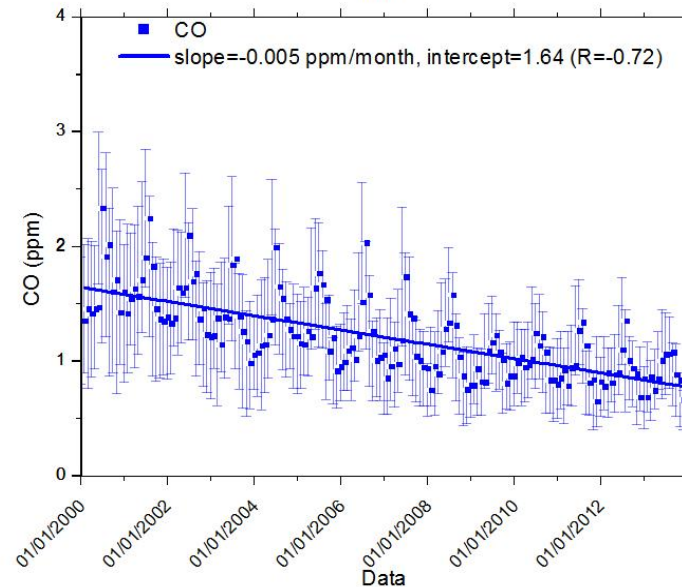
PM₁₀



O₃

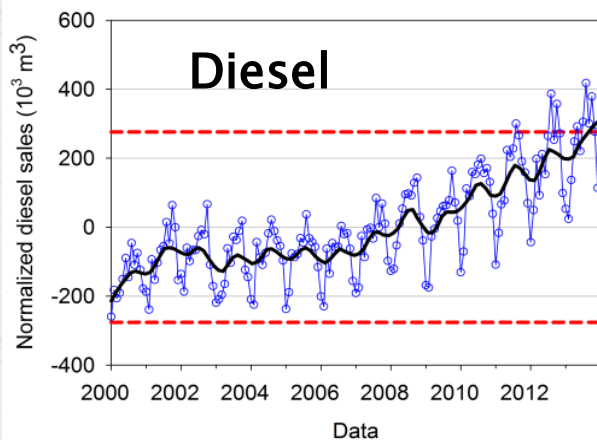
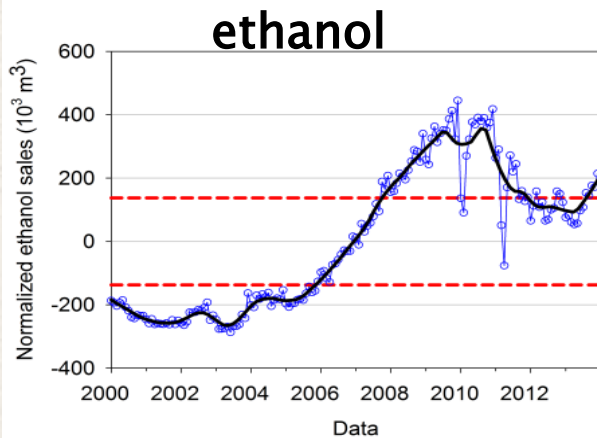
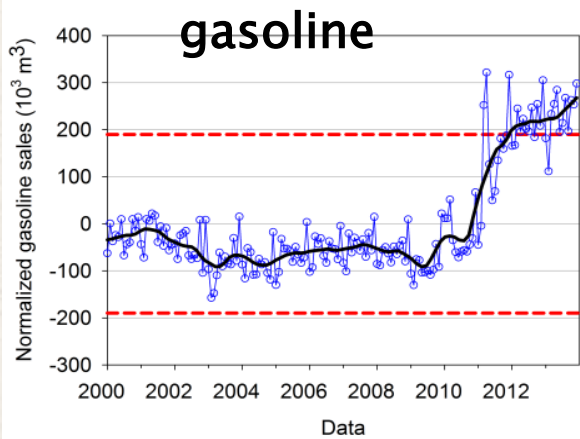


CO

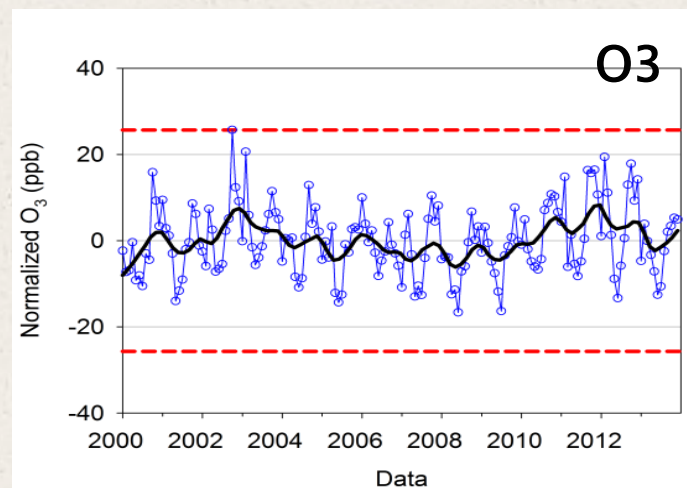
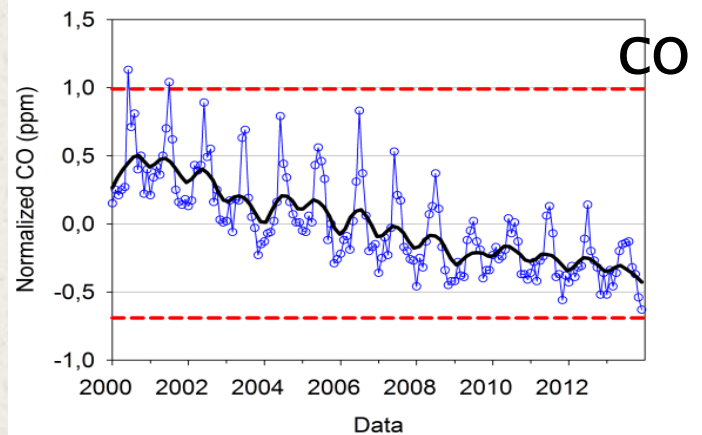
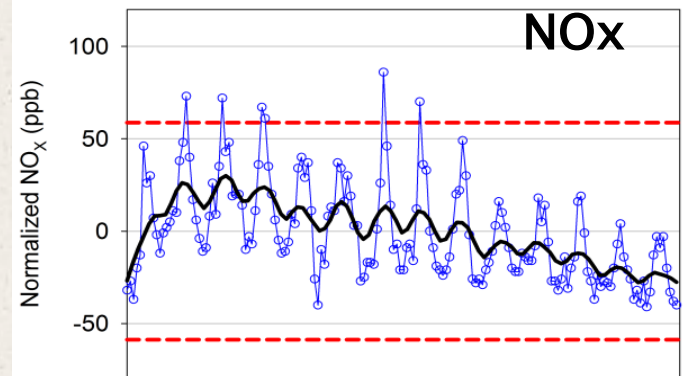


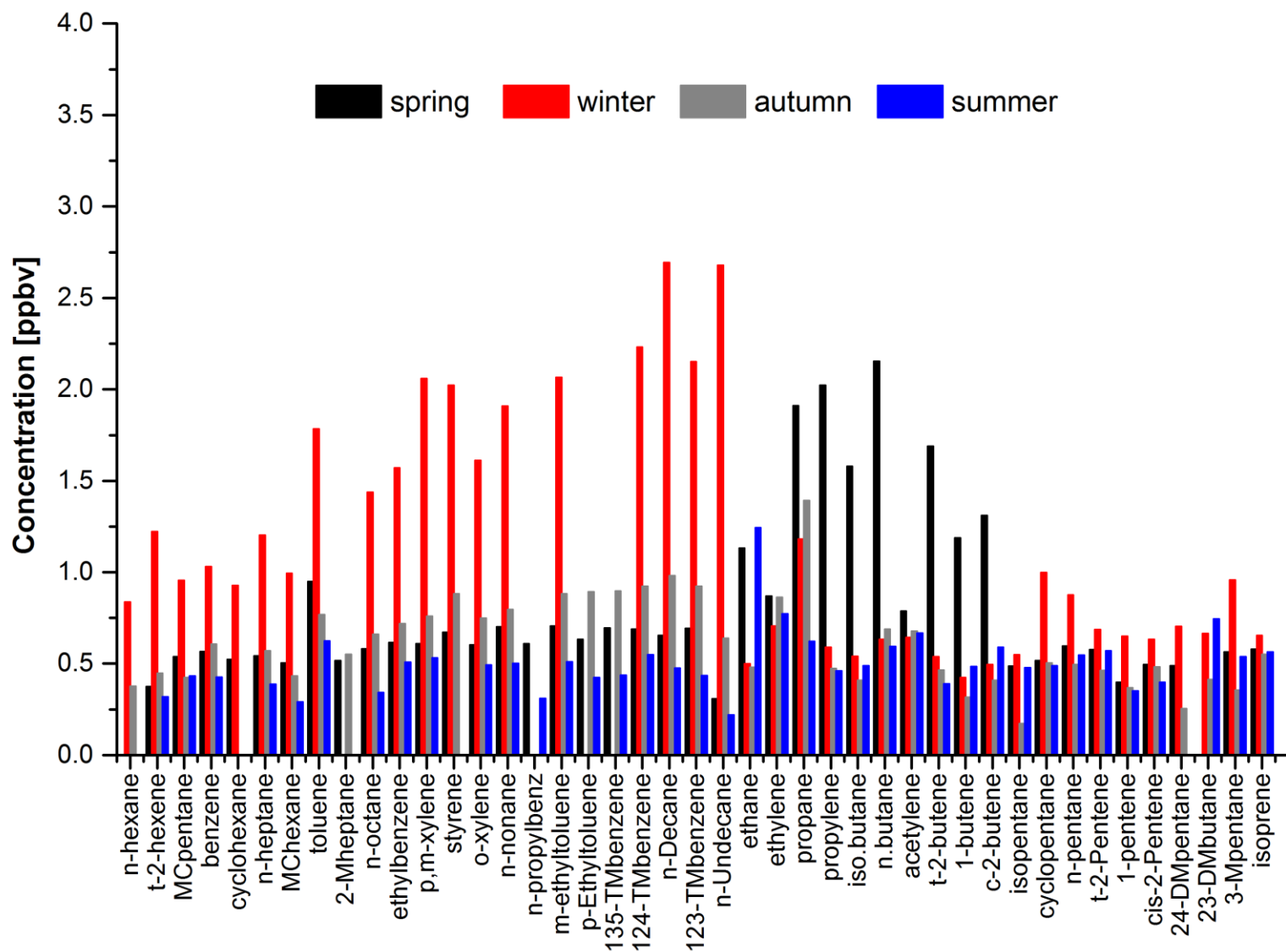
Monthly variations of selected air pollutants in São Paulo. Solid regression lines show monthly mean concentrations. Data are from the São Paulo Environmental Company CETESB, 2000–2013

<http://www.cetesb.sp.gov.br/ar/qualidade-do-ar/32-qualar>

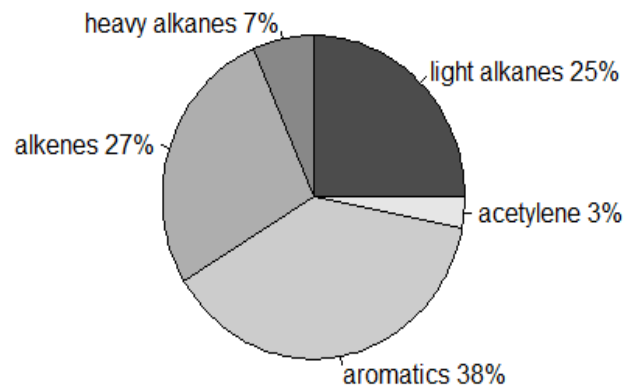


Plots in the left panels show the monthly mean fuel sales for gasoline (mean of $642.7 \cdot 10^3$ and standard deviation of $\pm 37.9 \text{ m}^3 \text{ month}^{-1}$), ethanol ($374.8 \cdot 10^3 \pm 27.5 \text{ m}^3 \text{ month}^{-1}$) and diesel ($854.1 \cdot 10^3 \pm 55.2 \text{ m}^3 \text{ month}^{-1}$), and the concentration for NO_x ($70.2 \pm 11.7 \text{ ppb}$), CO ($1.20 \pm 0.14 \text{ ppm}$) and O_3 ($70.2 \pm 11.7 \text{ ppm}$). The values are normalized to the long-term means. The black curves are monthly weighted regression smoothing fits.

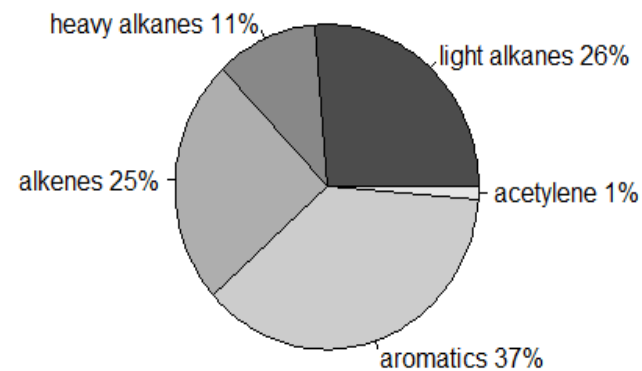




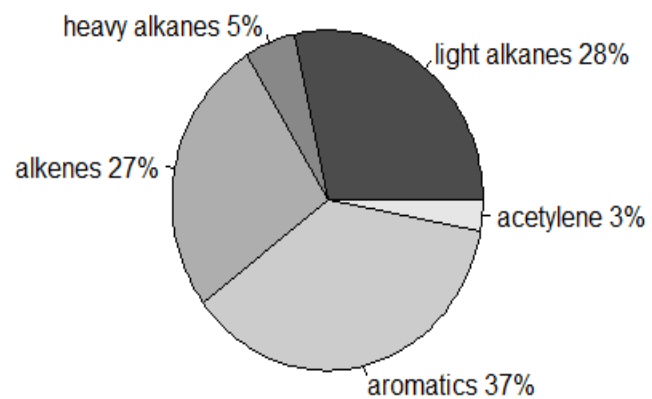
Autumn



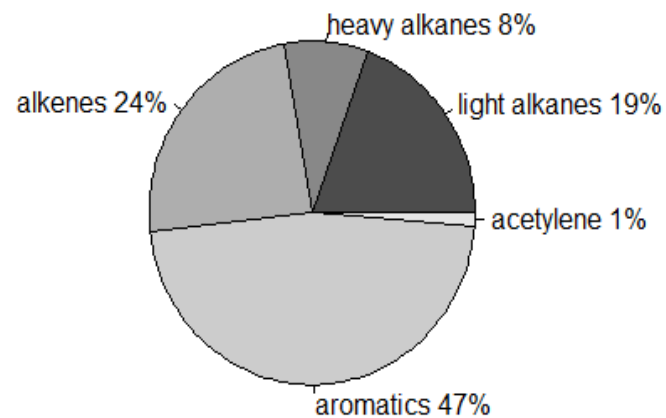
Spring



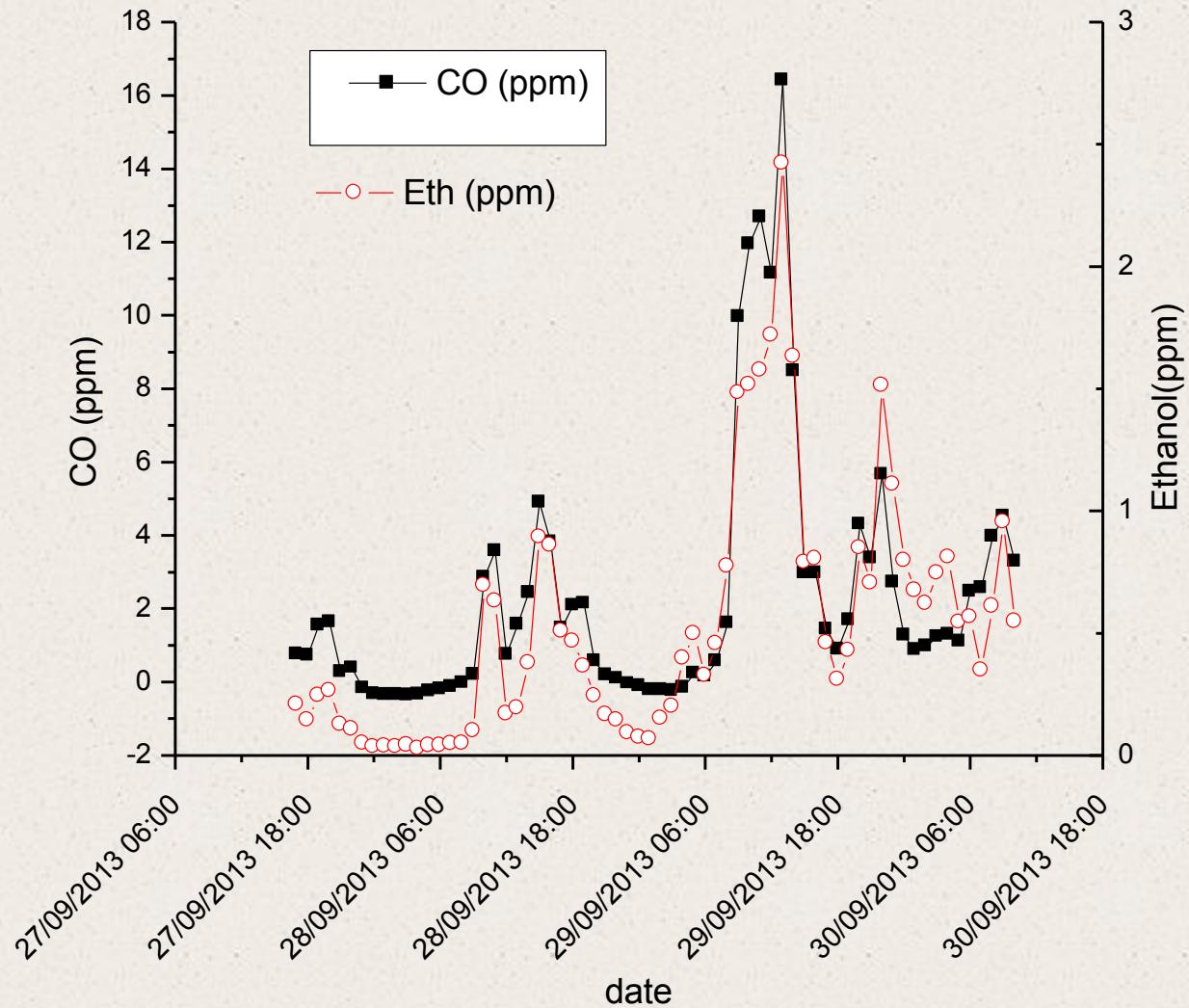
Summer



Winter



Ethanol and CO measurements



Emission characterization

Emission Factor Evaluations

Tunnel Measurements



TUNNEL JANIO QUÁDROS



Rodoanel Tunnel

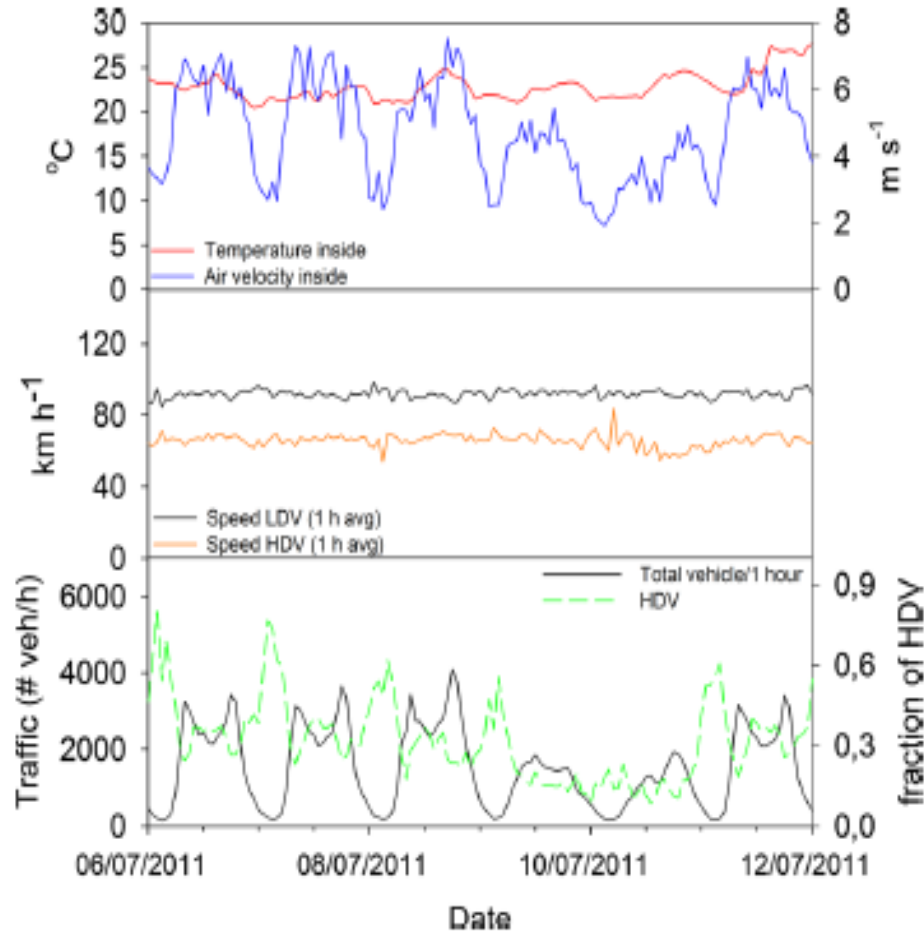


Fig. 1 Temperature, air speed, vehicle speed, traffic density and vehicle fleet composition, discrimination between LDV and HDV, during the measurements in the Rodoanel tunnel (TRA)

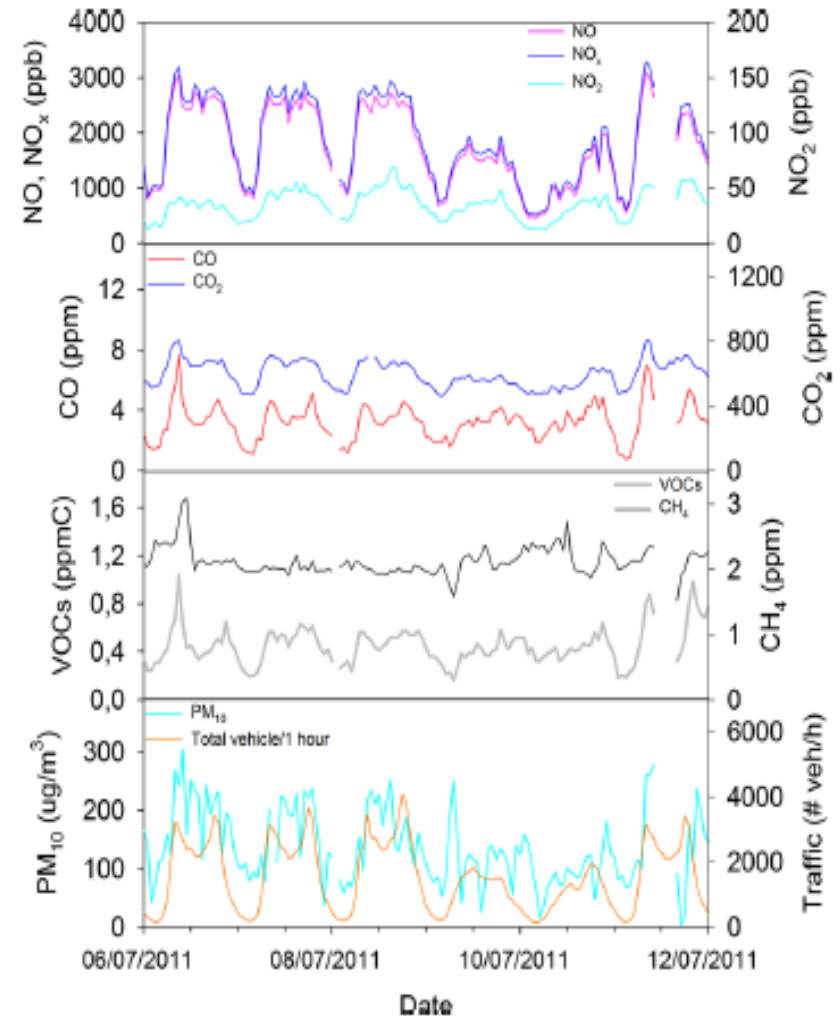
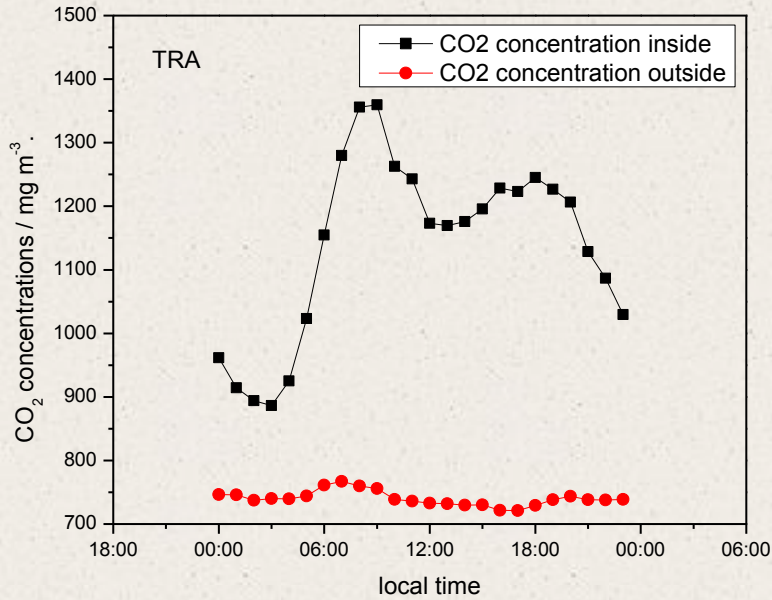
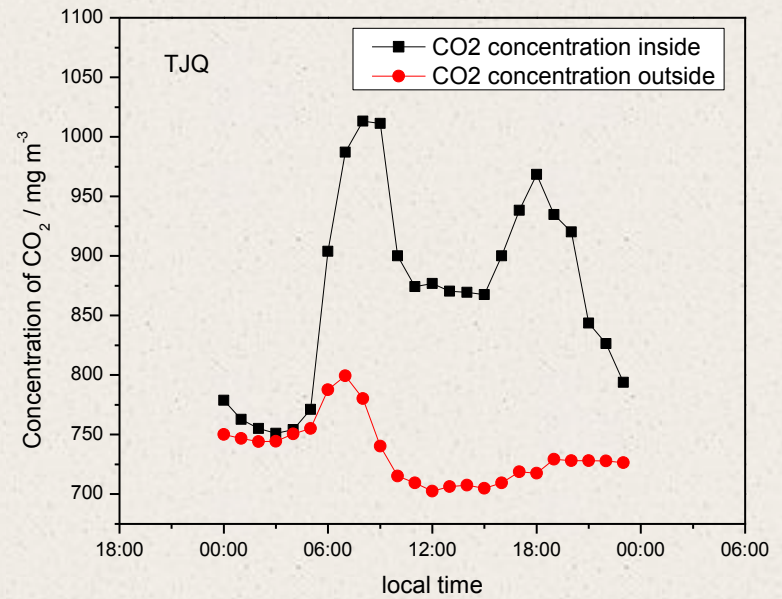


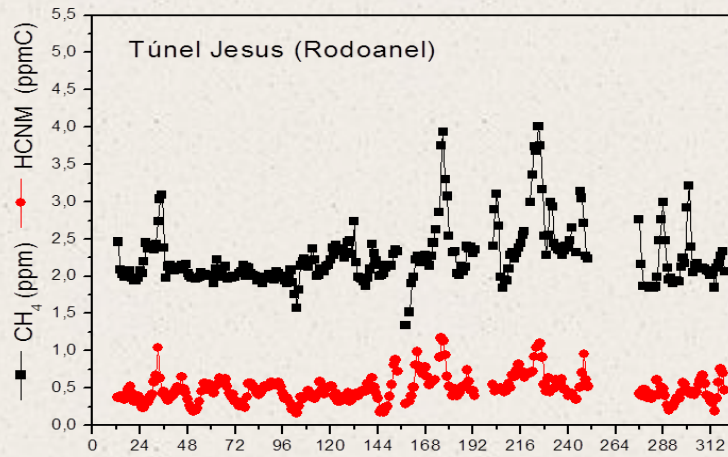
Fig. 2 Time variations of the researched gas and particulate-associated compounds inside the Rodoanel tunnel (TRA)



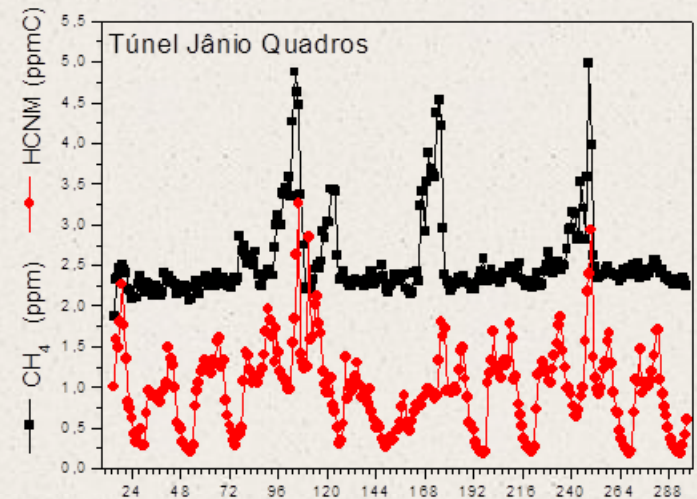
Heavy duty



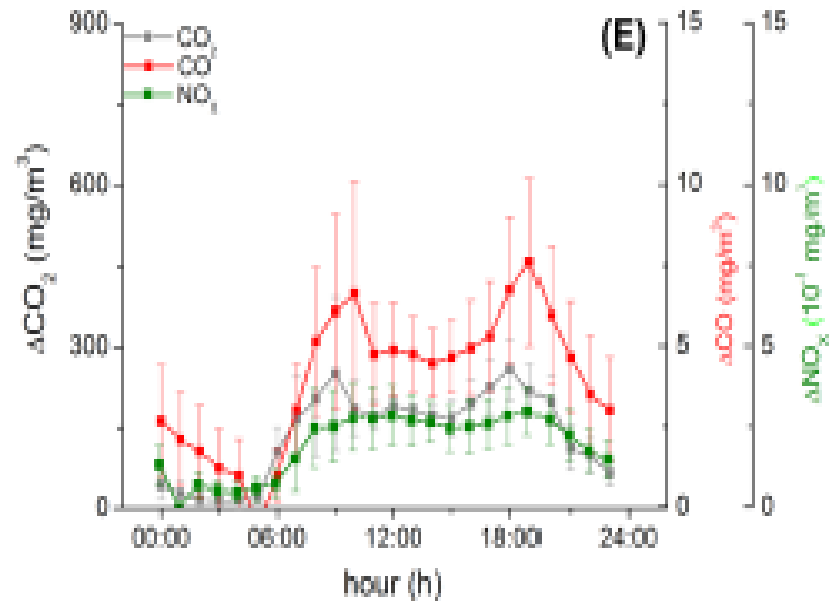
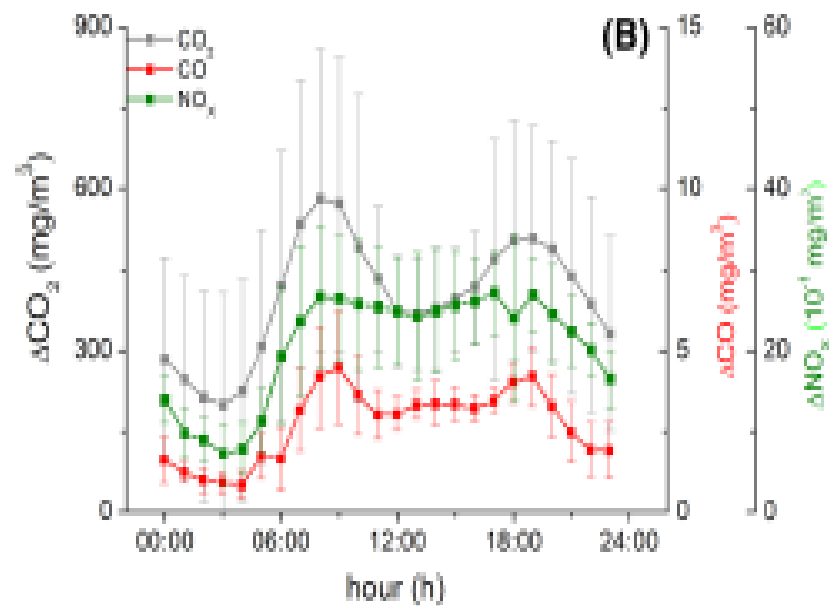
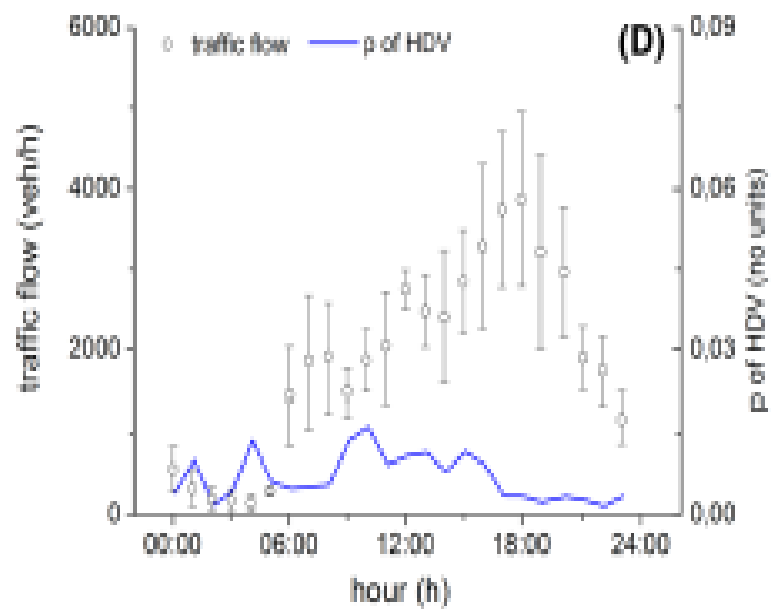
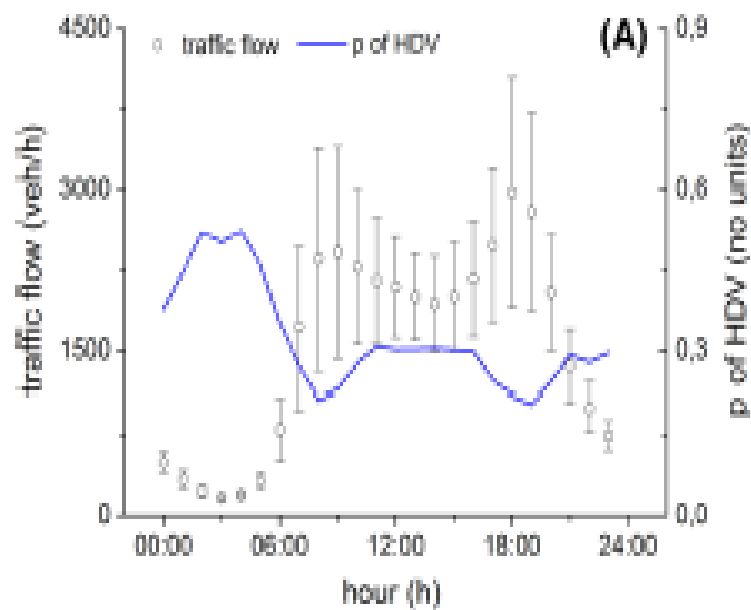
Light duty



July 2011



May 2011



Heavy-duty

Light-duty

Pérez-Martínez et al.
(2013)

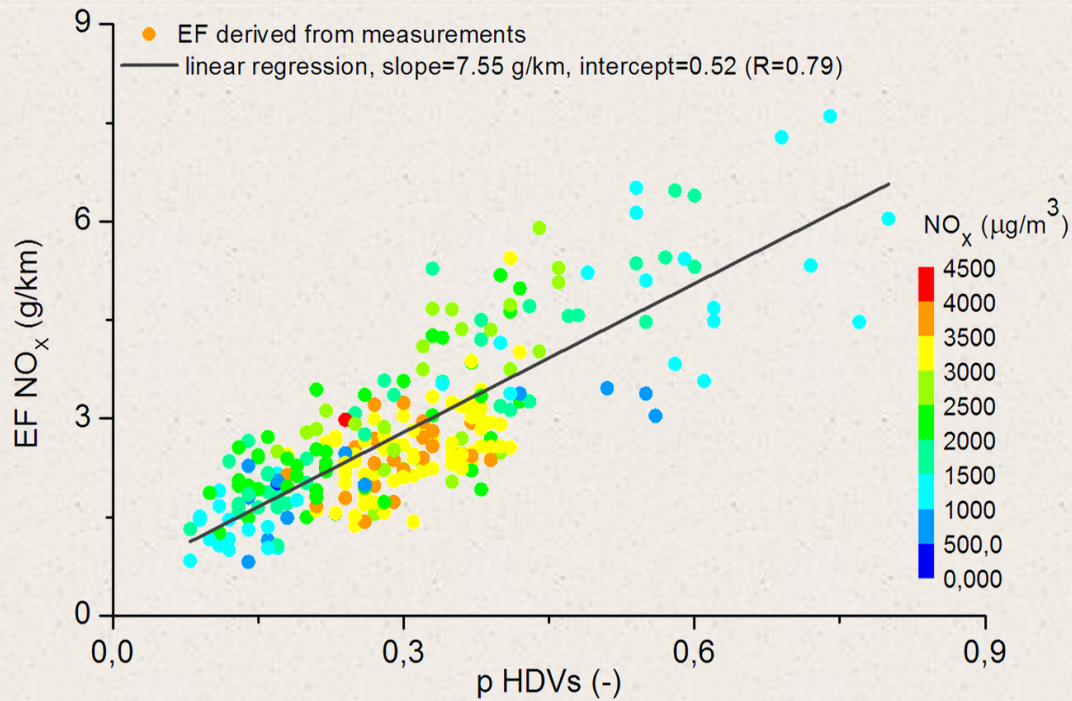
Emission Factor variation from 2004 to 2011

Vehicle type	Locale, year	CO (g km ⁻¹)	NO _x (g km ⁻¹)	SO ₂ (g km ⁻¹)	CO ₂ (g km ⁻¹)
LDV	JQT, 2011 ^a	5.9 ± 0.8	0.48 ± 0.04	0.021 ± 0.003	245 ± 1
	JQT, 2004 ^b	14.6±2.3	1.6±0.3	n.a.	n.a.
HDV	RT, 2011 ^a	4.0 ± 0.5	17 ± 1	0.48 ± 0.04	2257 ± 1
	MMT, 2004 ^b	20.6 ± 4.7	22.3 ± 9.8	n.a.	n.a.

Vehicle type	Locale, year	Formaldehyde (mg km ⁻¹)	Acetaldehyde (mg km ⁻¹)	n-hexane (mg km ⁻¹)	Benzene (mg km ⁻¹)	Toluene (mg km ⁻¹)	o-Xilene (mg km ⁻¹)
LDV	JQT, 2011 ^a	5.7 ± 1.7	7.4 ± 2.7	12.3 ± 5.7	8.0 ± 3.6	4.4 ± 0.9	10.1 ± 3.0
	JQT, 2004 ^b	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
HDV	RT, 2011 ^a	24.0 ± 8.1	7.6 ± 4.0	149 ± 75	222 ± 88	49 ± 12	163 ± 75
	MMT, 2004	48.4± 35.1	45.7 ± 29	60.1 ± 62.7	78.3 ± 72.0	134.5 ± 135.4	44.4 ± 39.8

MMT, Maria Maluf tunnel, ^aThe present study, ^bMartins et al 2006⁴.

Emission factors (EFs) NO_x vs. p HDVs



Emissions SPMR (HC, CO, NO_x , MP, SO_x)
 ≈ 805 t/day (88%, traffic)

Emission factor – Particles

Vehicle type	Locale, year	BC(PM _{2.5-10}) (mg km ⁻¹)	BC(PM _{2.5}) (mg km ⁻¹)	PM _{2.5-10} (mg km ⁻¹)	PM _{2.5} (mg km ⁻¹)
LDV	JQT, 2011 ^a	7 ± 6	39 ± 17	88 ± 36	45 ± 18
	JQT, 2004 ^b	n.a.	16 ± 5	127 ± 67	92 ± 20.
HDV	RT, 2011 ^a	53 ± 31	231 ± 98	110 ± 74	326 ± 119
	MMT, 2004 ^b	n.a.	462 ± 112	715 ± 585	588 ± 364

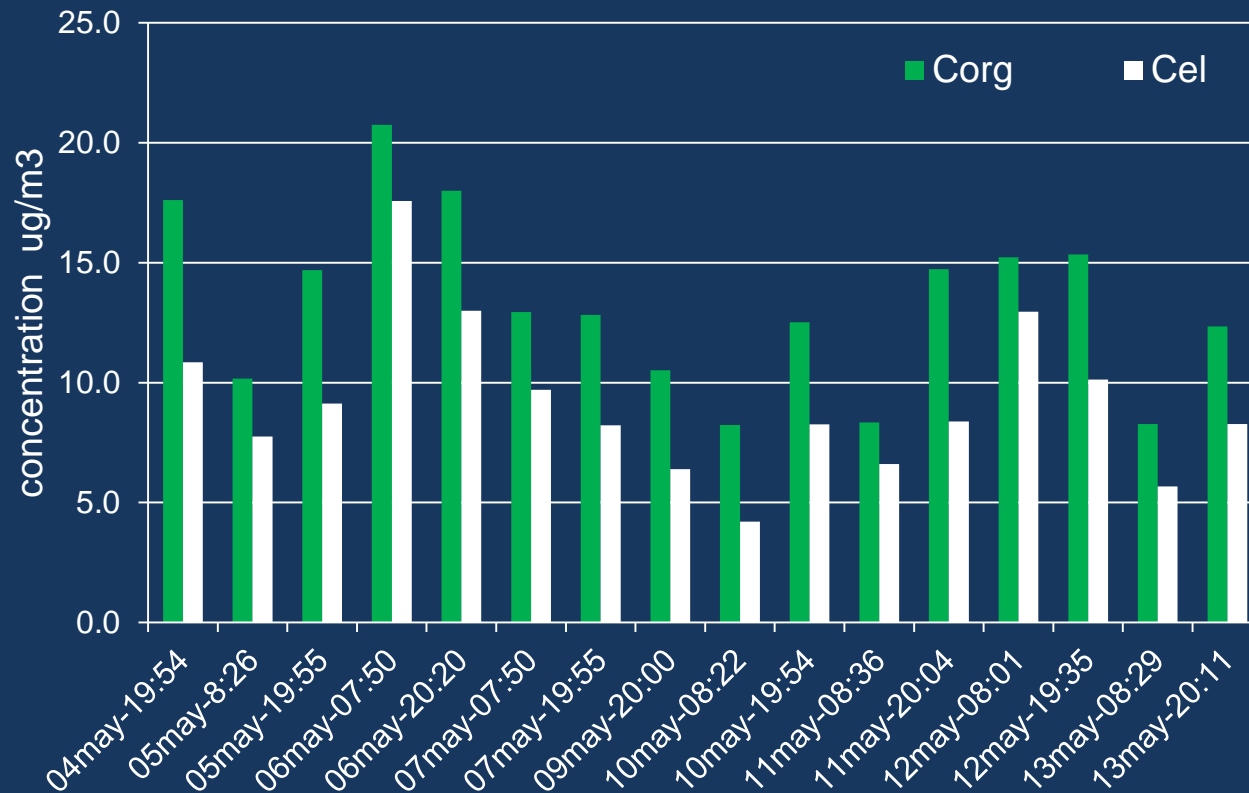
✓CO₂, CO, NO_x and SO₂ were measured hourly.

✓VOCs were collected every 2-hour.

✓PM_{2.5} and PM_{2.5-10} samples were collected every 6-h (daytime) and 12-h (overnight).

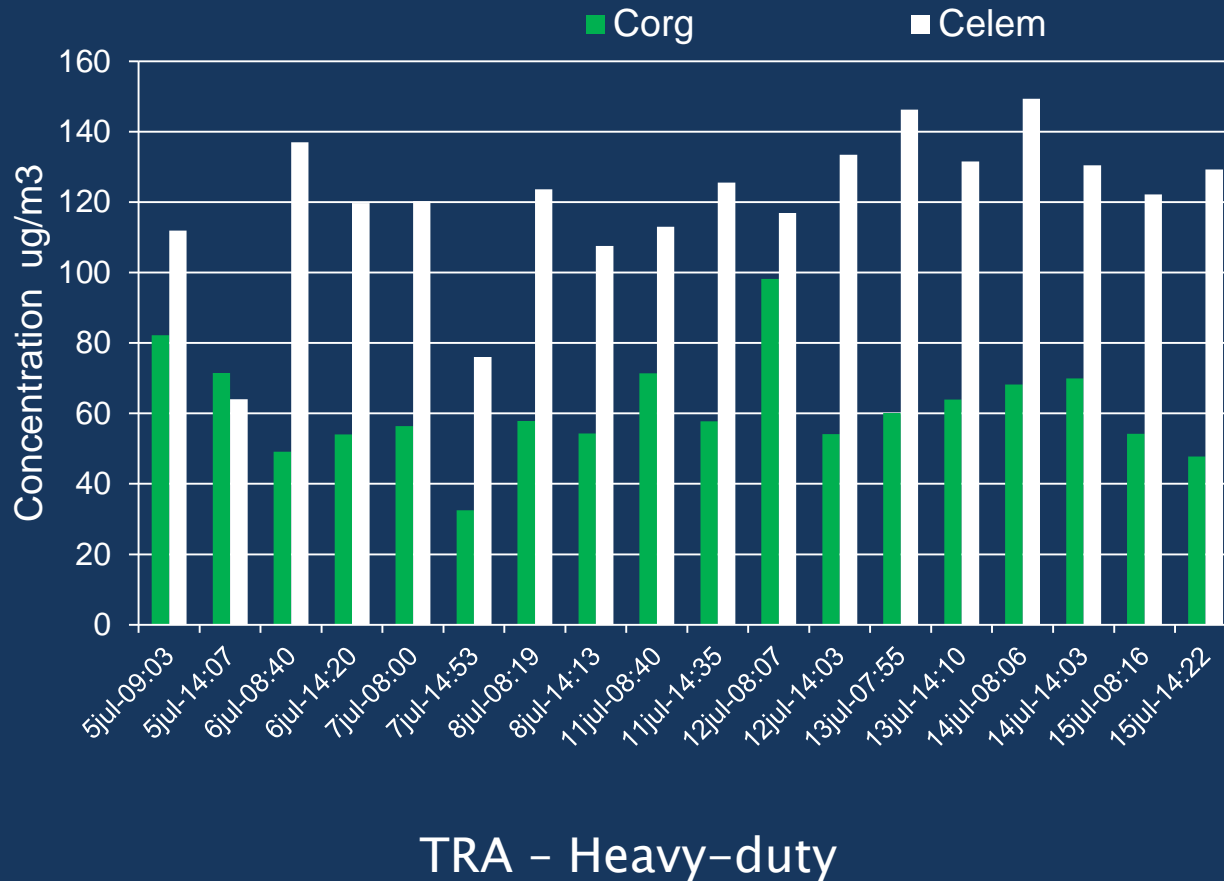
Sanchez–Ccoyllo et al, 2007

Measurements of carbonaceous compounds Elemental and Organic



TJQ – Light-duty

Measurements of carbonaceous compounds Elemental and Organic



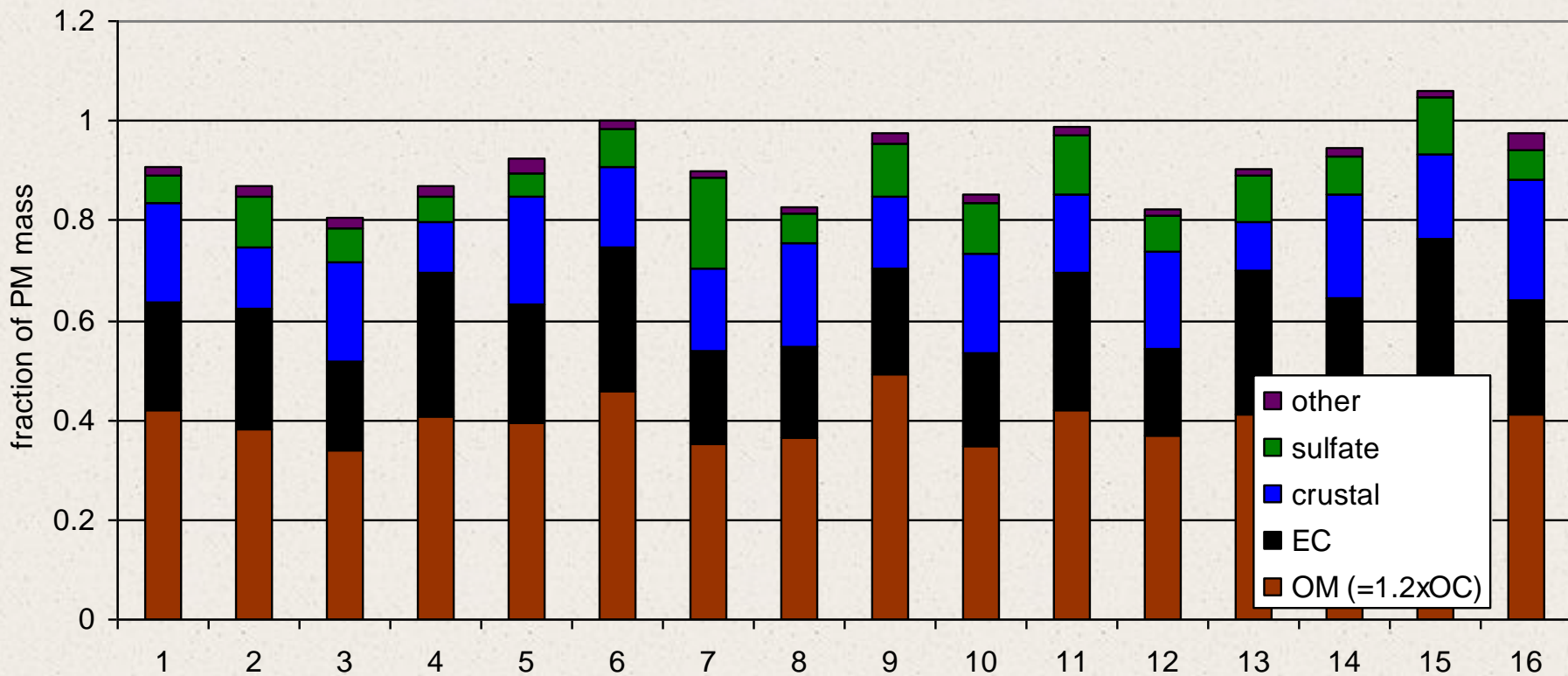
Mass balance calculations

- organic matter considered as 1.2 times OC
- assumed all S is sulfate
- used the following formula for crustal (takes into account oxides)

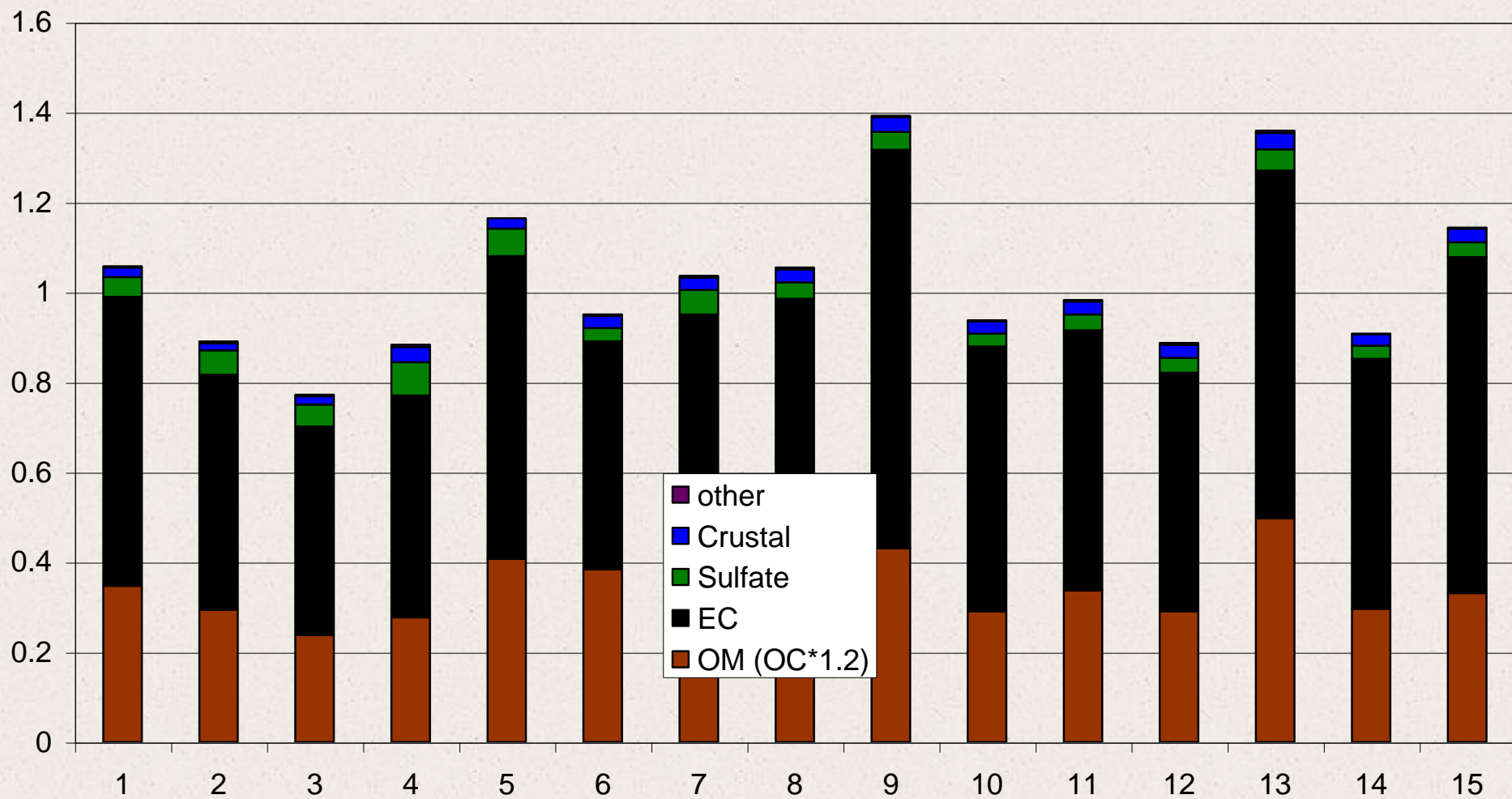
$$\text{Crustal} = 1.89 \times \text{Al} + 2.14 \times \text{Si} + 1.4 \times \text{Ca} + 1.36 \times \text{Fe} + 1.2 \times \text{K} + 1.67 \times \text{Ti}$$

- all other composition data (e.g. Cu) went into “other

Mass Balance for PM2.5 – Light Duty



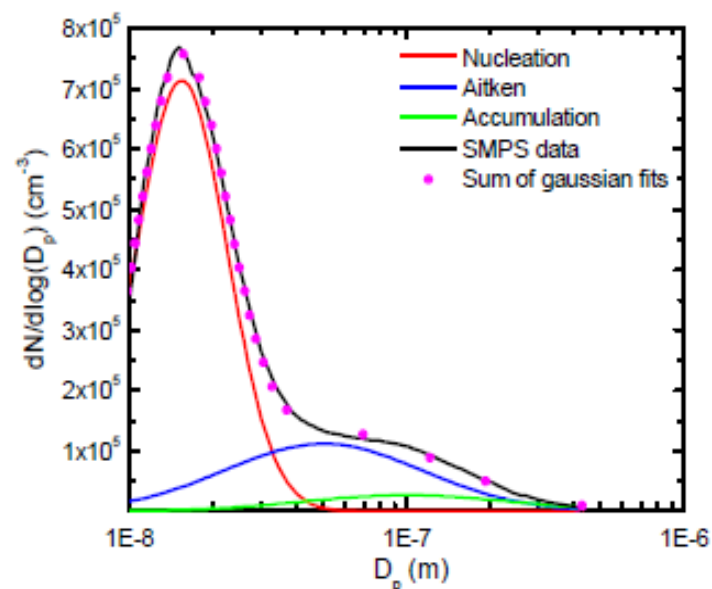
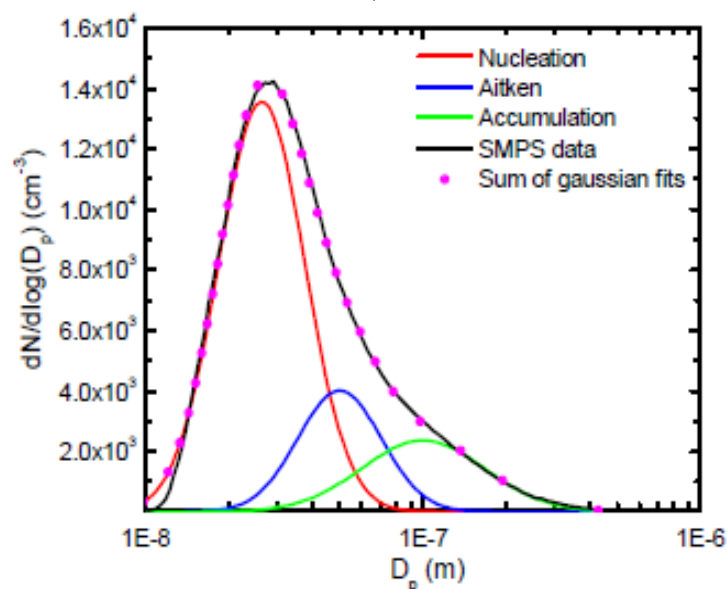
Mass Balance for PM2.5 – Heavy duty



Light duty fleet

Diesel

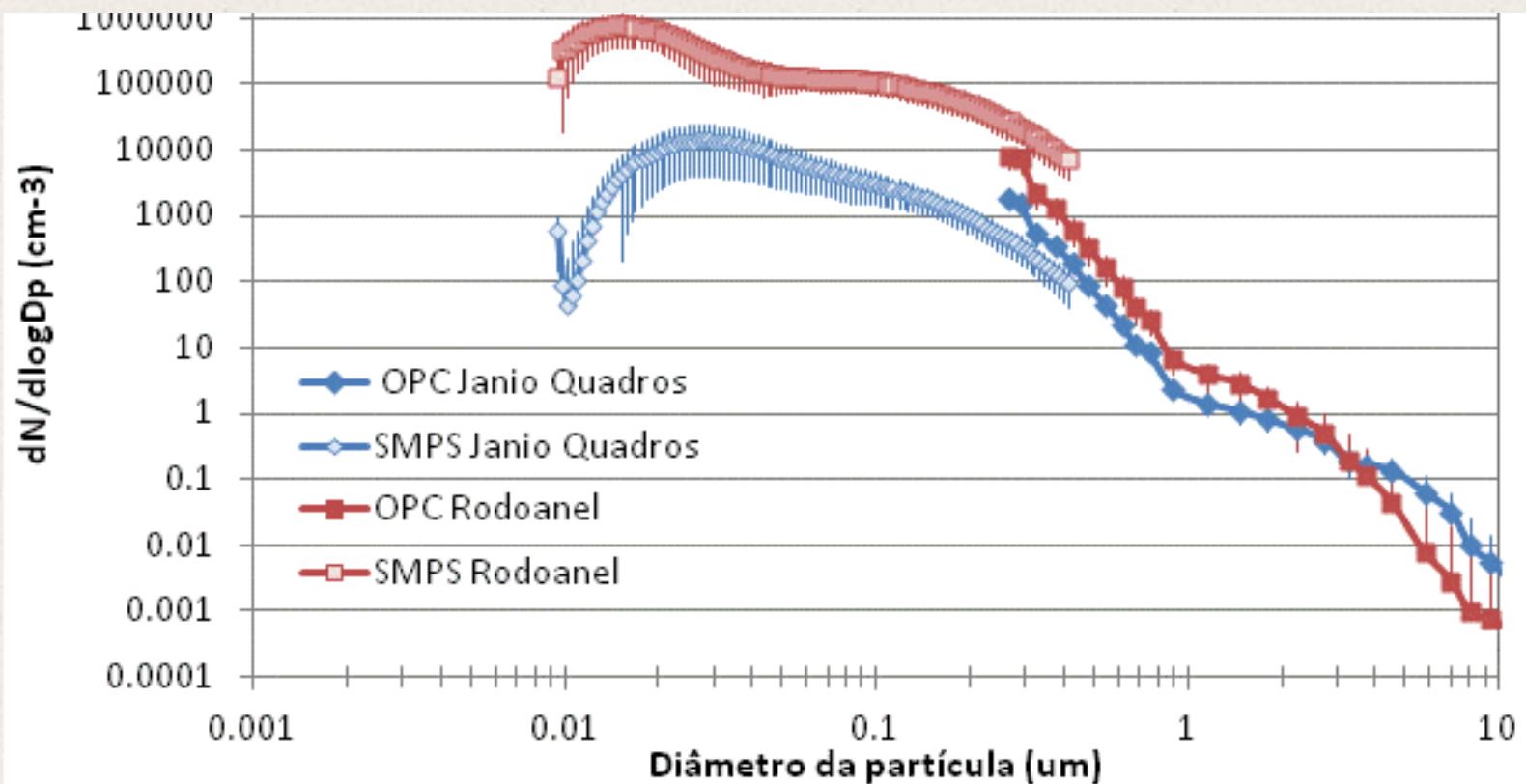
Aerosol size
distribution



Average particle number
concentration 73000cm^{-3} and
 $d=48.4\text{nm}$

Average particle number
concentration 366000cm^{-3} and
 $d=38.7\text{nm}$

Number Size distribution of particles – Tunnel SMPS + OPC



CONCLUSIONS

- Air concentrations allow **space/temporal** identification road transport **sources GHGs/ATPs**
- Results contribute to define **measures/policies** to improve **air quality & life**
- **Extrapolation** local inventories to other cities will impact spatial distribution ATPs in areas **around large urban**
- **Estimated vs. measured air concentrations**: higher GHGs/ATPs have pronounced diurnal profiles

- Transport activity generate temporal & spatial **schemes** useful for regional dispersion **air pollution modelling**
- This study computes emission inventories by generating **Emission Factors (EFs)** & provides tools to **complement global emission inventories (GEIs)**

Modeling approach for emission

Source distribution Noturn Light DMSP-OLS

Source distribution

Grid points with 30 seconds resolution
from -180° to 180° longitude and -65°
to 65° latitude

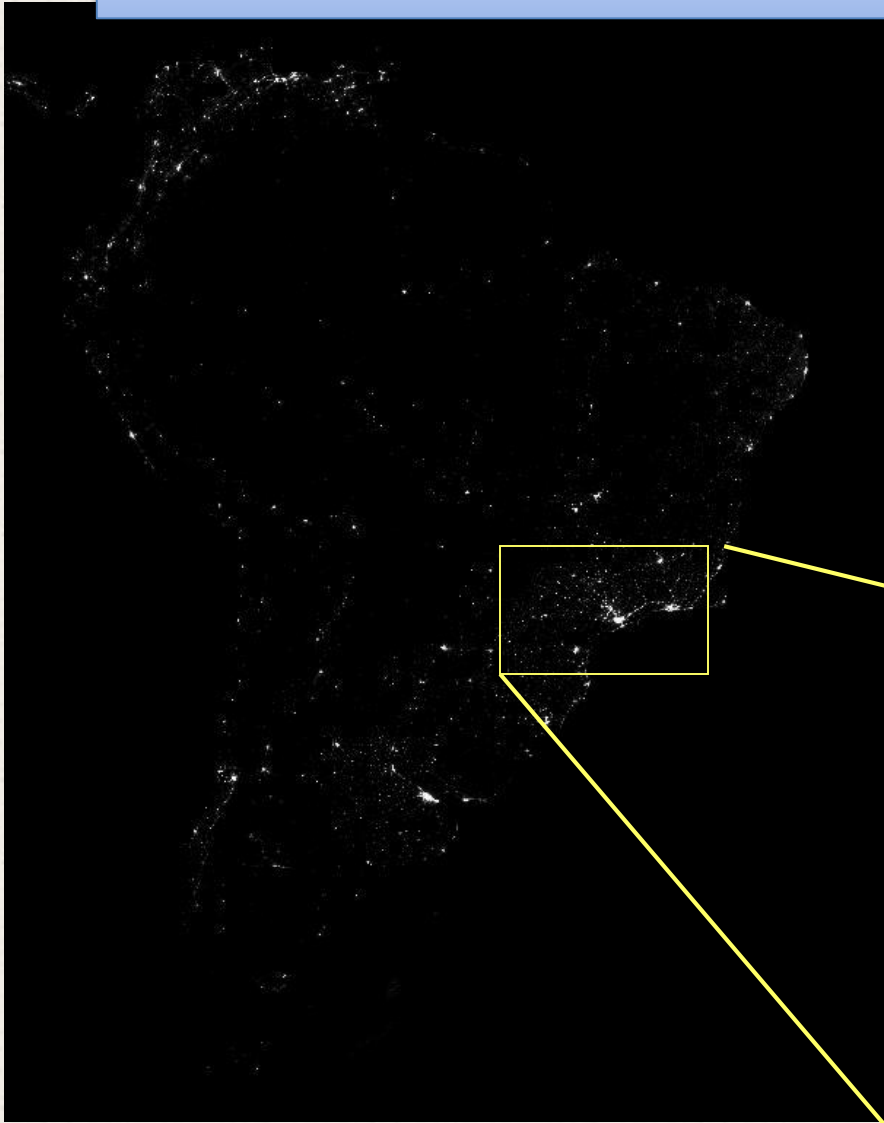


Image and data from NOAA's National
Geophysical Data Center.

Spatial distribution of roads in South America - preliminar



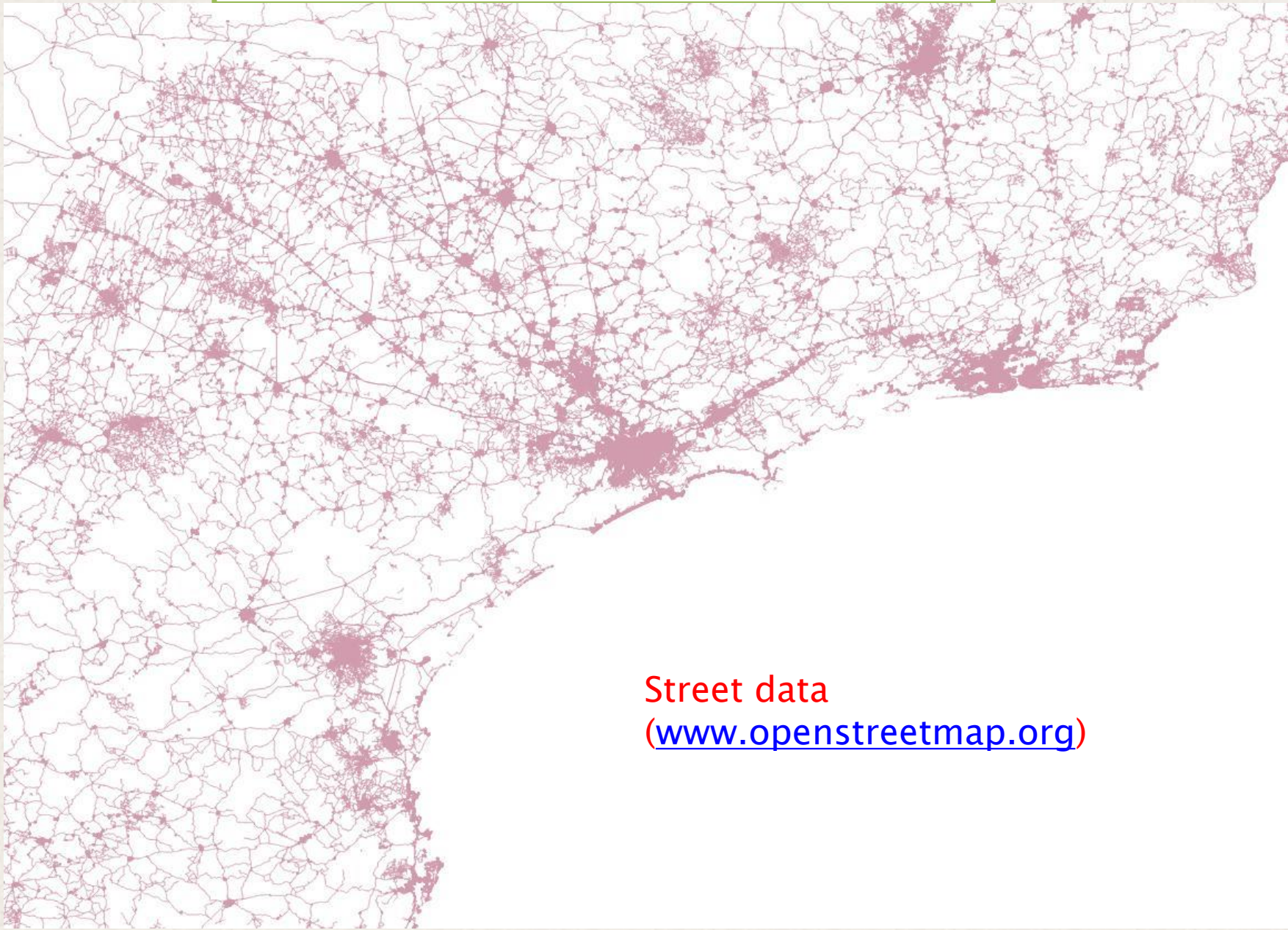
Geographic information from Open Street Maps



Figura 4. Informação geográfica no open Street Maps

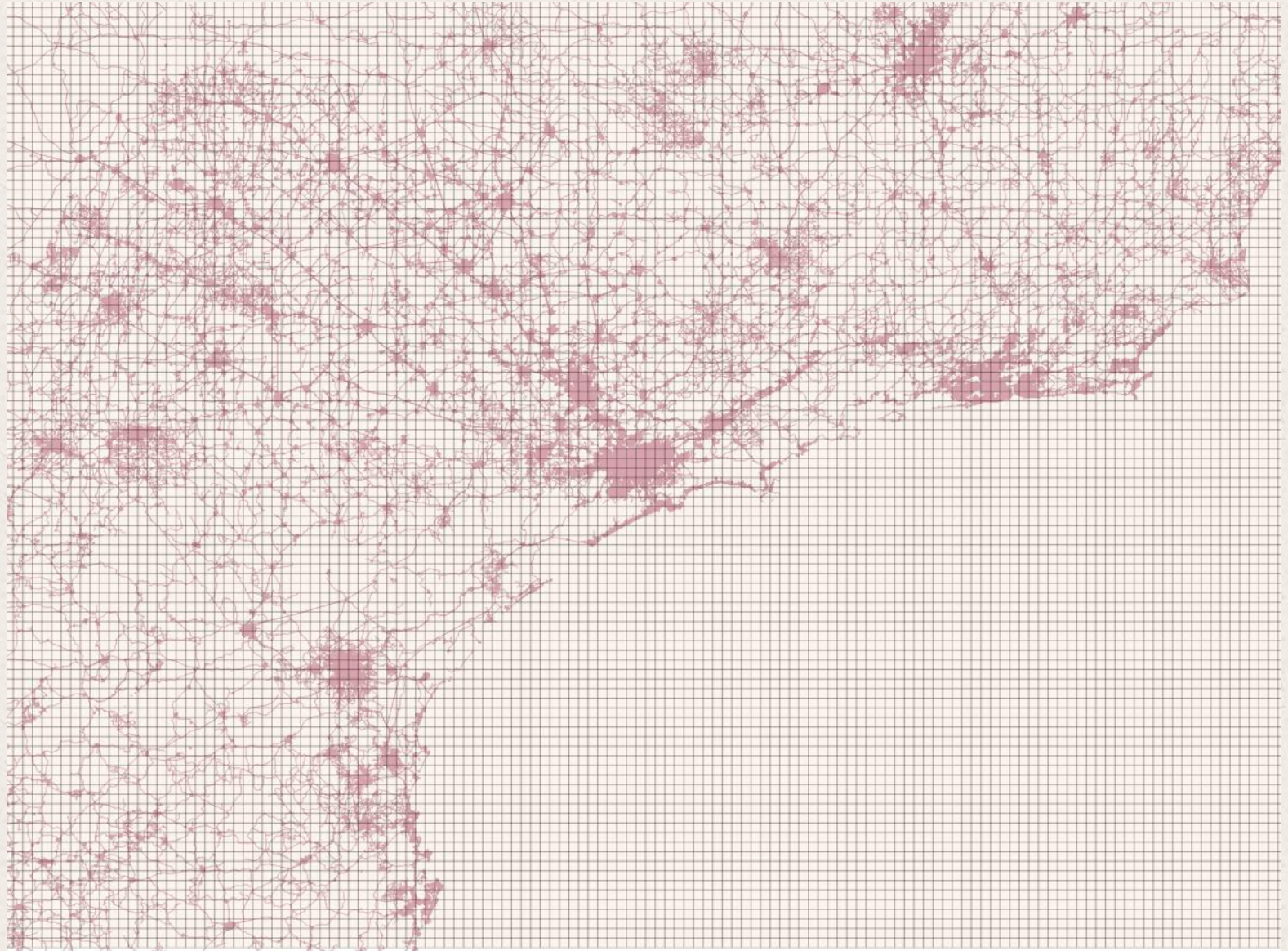
- Road
- Main street
- Primary street
- Secondary street
- street

Spatial distribution of emissions

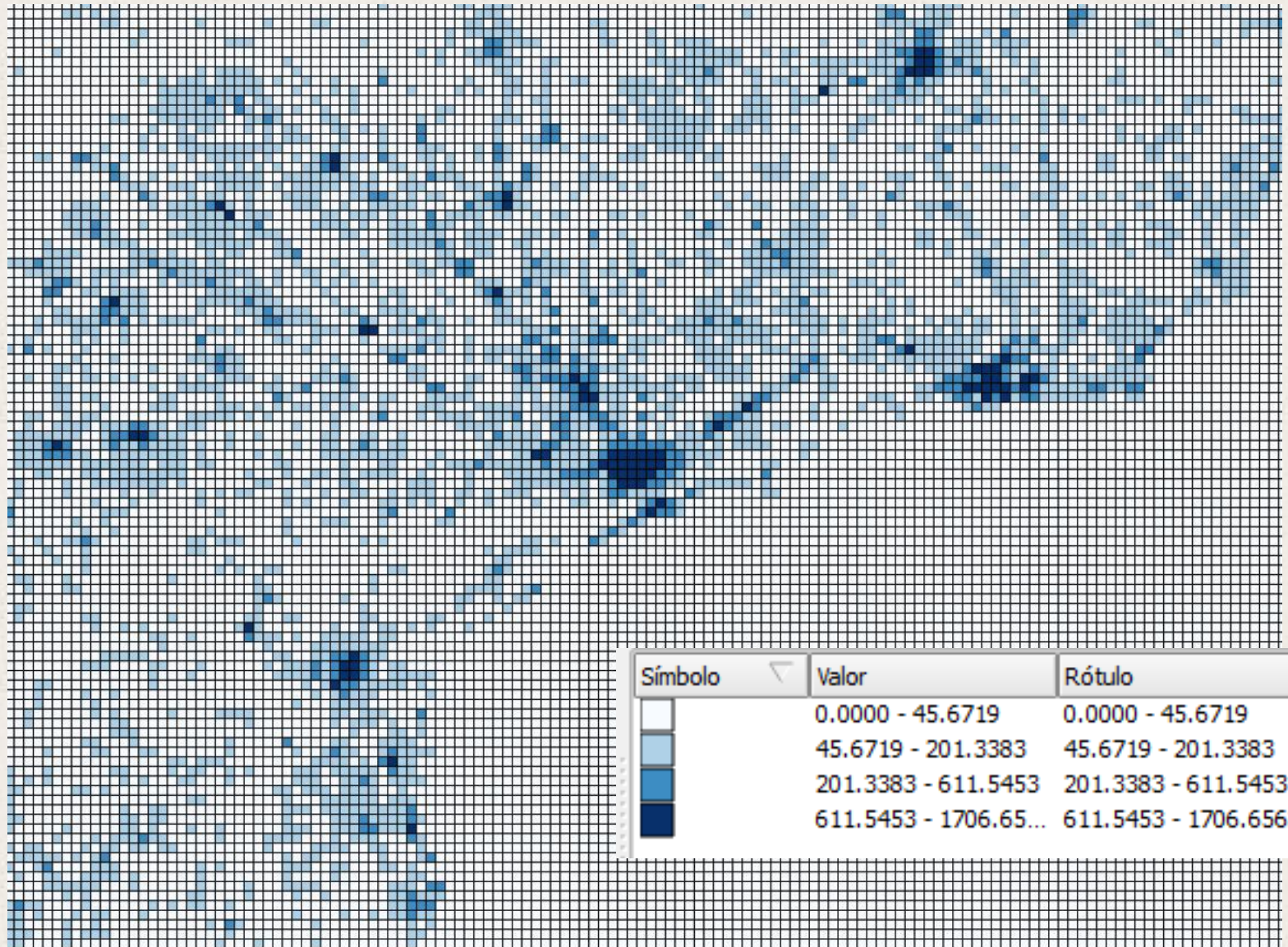


Street data
(www.openstreetmap.org)

Grid 9km x 9km

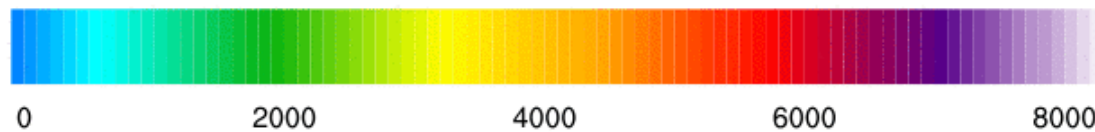
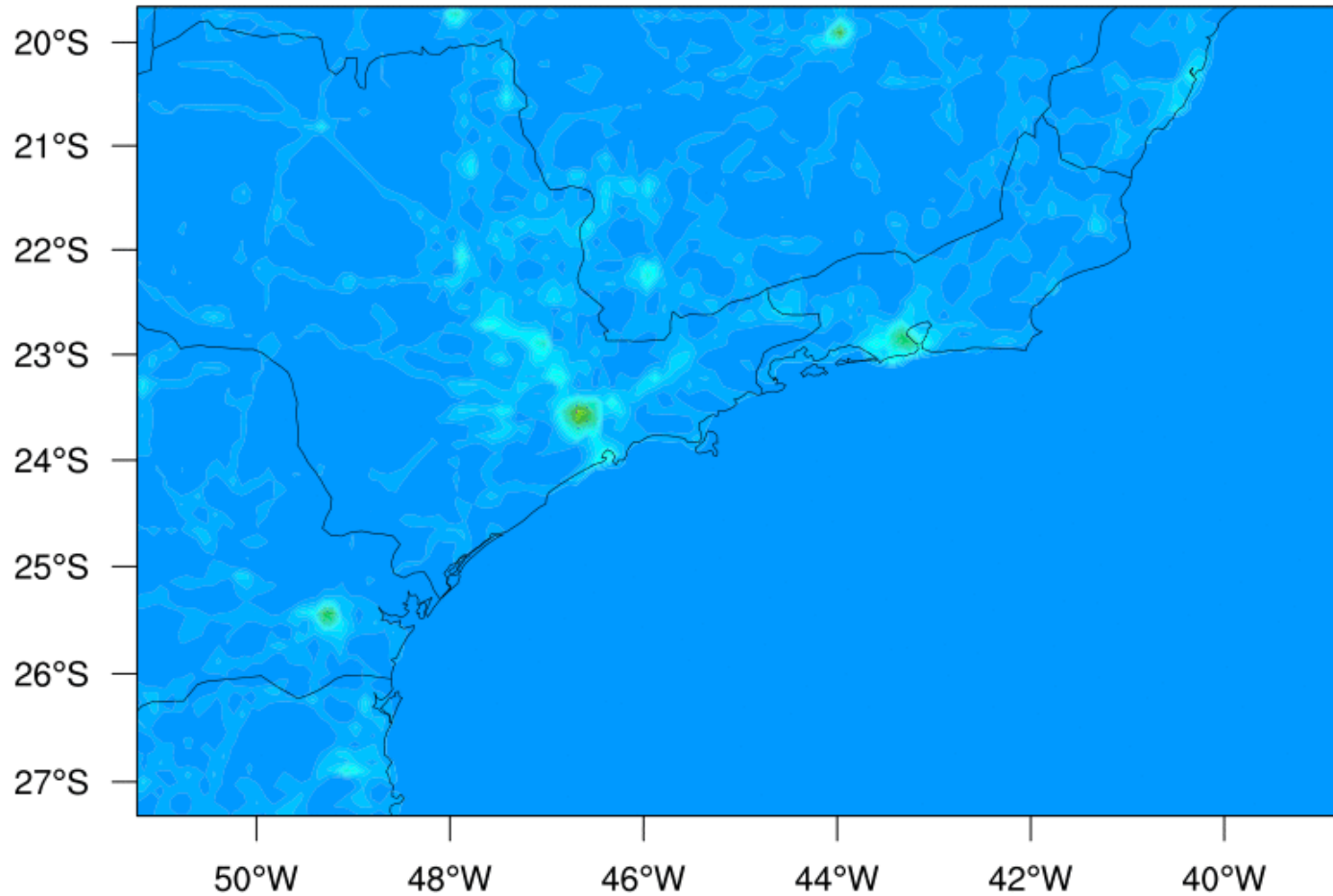


Density (km of street\grid)
number of vehicles proportional to the density



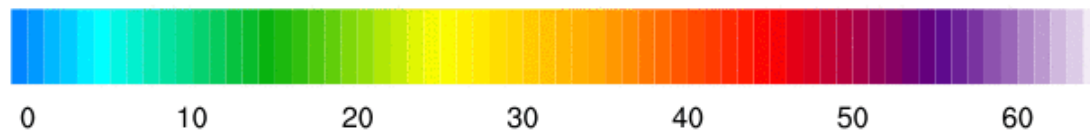
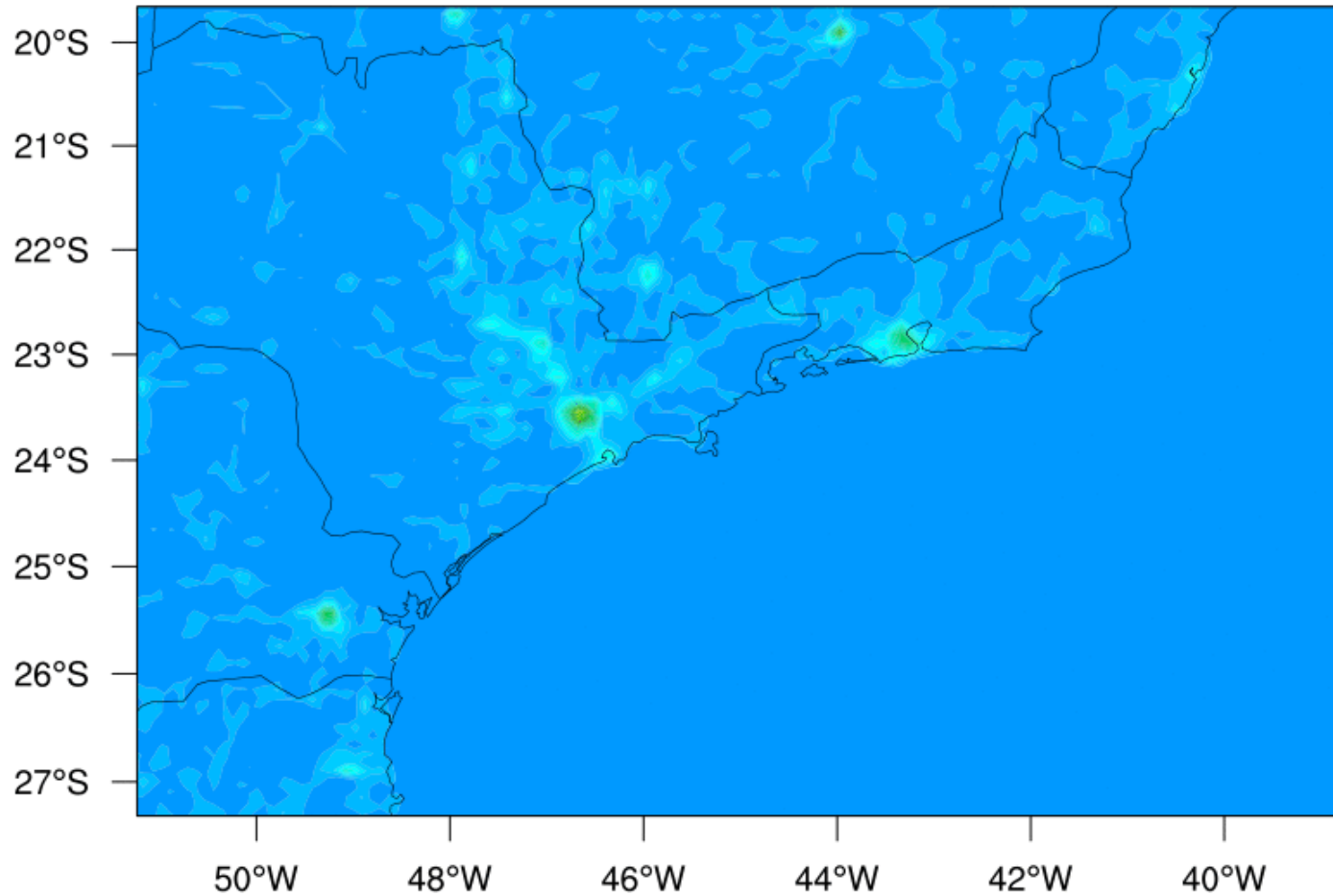
CO EMISSIONS (mol km⁻² hr⁻¹)

00:00



NO2 EMISSIONS (mol km⁻² hr⁻¹)

00:00



Acknowledgements

FAPESP, CNPq, CETESB, IAG/USP

